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NONDESTRUCTIVE AND FRACTURE EVALUATION SECTION 1988 REVIEW AND 1989 WORK PROGRAM

Report No. 89-85-K

B. Mukherjee
Acting Section Head

ABSTRACT

The projects and achievements of the Nondestructive and Fracture Evaluation Section in 1988 are reviewed. Proposed projects and objectives for 1989 are described in outline.

job	file	date	report no.
	826.0	April 28, 1989	89-85-K

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EXECUTIVE SUMMARY

NONDESTRUCTIVE AND FRACTURE EVALUATION SECTION 1988 REVIEW AND 1989 WORK PROGRAM

Report No. 89-85-K

B. Mukherjee
Acting Section Head

As in previous years, the NDE Unit has concentrated on pressure tube inspection. The work programs have ranged from building inspection systems to more basic research. As examples of the engineered systems, a CIGAR multiplexer, STEM device and Pickering Bioshield inspection head were constructed. Late in the year, there were requests for a Pickering BLIP, and laser-heated measurement of the annulus gas flow at the pig-tails. At the other end of the spectrum, research on digital signal processing techniques was performed on Wigner transforms, synthetic aperture focussing, deconvolution, and eddy current algorithms. In reactor measurement of blister crack depths by ultrasonic crack tip diffraction is steadily becoming a reality. Ultrasonic methods of measuring hydrides showed progress this year, with differential velocity measurements showing great potential and birefringent shear waves able to detect uncracked blisters. Acoustic emission on leaking pressure tubes is progressing, with the ability to capture and record waveforms. An on-power eddy current coil (SLAP) is being built, and an ultrasonic steam generator tube inspection system is being designed.

The Fracture Mechanics Unit concentrated on projects to support the operation of nuclear and thermal plants. A pressure tube burst test facility was fully commissioned. A number of experiments were conducted on tubes containing external axial surface cracks. A computer program for the evaluation of pressure tubes containing flaws has been written for Central Production Services as a part of the on-going technology transfer effort. A high pressure and high temperature autoclave is also being commissioned to fatigue test Zr-Nb specimens in operating environment.

The Unit's effort on Darlington Leak-Before-Break (DLBB) focussed on providing analytical support to the Design & Development Division on three dimensional elastic plastic fracture mechanics analysis of reactor inlet and outlet headers containing through wall cracks. A new set of J resistance material curves was obtained for a 22" pipe elbow and a 21" NPS Sch 100 pipe. A fatigue crack growth computer code was also developed for the DLBB project.

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Support work for thermal plants expanded significantly in 1988. Flaws were detected in the boiler circulation pump casings, discharge valve bodies and pump suction manifold in Units 1 and 3 of Lambton TGS. Flaws were also detected in the inlet economizer header in the Lambton TGS Unit 1. The deepest flaws were repaired. Fracture mechanics evaluations were performed to assess the safety margins for these components. Ductile fracture toughness tests were conducted on A216 Gr WCB cast steel to provide material input for the fracture mechanics evaluation.

Many vessels currently in service at the Bruce Heavy Water Plant (BHWP) possess varying amounts of damage from internal hydrogen blistering which may be degrading the pressure containment. A fracture toughness test program was initiated on blistered steels from BHWP to help provide guidelines for safe operating limits and retirement criteria for hydrogen blistered pressure vessels. Work on life assurance of nuclear plants and life extension of thermal plants was also initiated.

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To Dr. D. Mills
Director of Research

NONDESTRUCTIVE AND FRACTURE EVALUATION SECTION
1988 REVIEW AND 1989 WORK PROGRAM

I - INTRODUCTION

In previous years, the Section had significant difficulty in fulfilling its OM&A work program due to heavy client demands in both nondestructive evaluation and fracture mechanics. One of the major goals of the Section in 1988 was to increase the Research Division funded forward looking work to 50% of its total labour budget. The Nondestructive Evaluation (NDE) Unit was able to achieve this goal. However, the Fracture Mechanics Unit's client funded work continued to be higher than the goal set for the Unit and Class 0-2 projects accounted for 70% of its total labour budget. Most of these projects were in support of plant licensing and operation and startup of nuclear and thermal plants and demanded highest priority due to regulatory and economic considerations. As a result, a Candu Owners Group (COG) funded program on pressure tube was postponed to 1989 and the Unit's planned OM&A work program was also reduced.

The highlights of the Section's 1988 work program is in this report, followed by the 1989 work program plan.

Section Personnel

Nondestructive Evaluation

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Nondestructive Evaluation Unit

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Attached Staff (University of Toronto)	Mr. K.-E. Lindenschmidt

*On attachment to BNPD.

The objectives and principal research interests of the Unit are:

- Design and Development of remotely operated, electromechanical scanning systems for nondestructive examination of nuclear station components to reduce man-rem expenditure and improve inspection reliability.

- Evaluation of new concepts and development of equipment to enable remote and precise spatial measurements in nuclear power stations.

- Research into limitations of, and applicability of, nondestructive testing techniques for defect detection and evaluation, particularly with regard to nuclear periodic inspection requirements.

- Development of new nondestructive techniques and procedures for particular applications at generating plants and transmission systems.

- Investigation of signal analysis methods for improved defect characterization.

- Assistance to operational groups with non-routine inspection problems, major system breakdowns, and service inspection requirements.

Fracture Mechanics

Unit Head – Fracture Mechanics	Dr. B. Mukherjee
Engineers	Mr. M.L. Vanderglas Mr. D.A. Scarth Mr. A.C. Wallace Mr. O.E. Lepik
Technologists	Mr. D.W. Carpenter Mr. D.M. McCluskey Mr. J. Schaefer

The objectives of the Unit are:

- Assess the impact of flaws and off-design operation of the reliability and safety of major plant components.

- Propose and evaluate new methodology for flaw-structure interaction analysis that will quantify the real margins of safety of pressure bearing components.

- Improve quantitative understanding of the effects of plant chemistries, materials and fabrication processes and stress state on performance of major plant components.

The main research interests of the Unit are:

- Research into experimental and computational aspects of fracture mechanics.
- Determination of fatigue and fracture properties of generating plant and transmission system materials under operating environmental conditions.
- Investigation of techniques for service life prediction of components.
- Development of new fracture mechanics analysis procedures where conventional techniques are inappropriate.
- Development of rapid structural integrity evaluation methods to meet jurisdictional requirements.

II - 1989 WORK PROGRAM REVIEW

1.0 NONDESTRUCTIVE EVALUATION

1.1 NDE Techniques R&D and Applications

Wigner Distribution Function for Ultrasonic Signal Analysis

A detailed analysis of the Wigner distribution function (WDF) was made with particular regard for its potential in ultrasonic NDE. This distribution provides a two dimensional joint time-frequency representation of a time domain signal. The WDF is similar in some respect to the spectrogram of speech analysis, the ambiguity function, and the short-time Fourier transform, but is in fact the most general case with the best time-frequency resolution from which all of these can be derived. Algorithms were developed for its calculation in the Asyst programming environment, and an analysis was made of its potential uses. The technique may be useful in the characterization of broadband ultrasonic transducers where the time dependence of the spectrum is important in the formation of the ultrasound field. An initial investigation of its ability to discriminate the multiple echoes returning from a sharp edged notch was inconclusive.

Synthetic Aperture Focusing Technique

The synthetic aperture focusing technique (SAFT) has been successfully demonstrated in the laboratory on the boiler manway geometry. The current implementation has a lower limit sizing ability of approximately 2.5 mm through 90 mm of steel, a significant improvement over a compound focused probe designed specifically for this geometry. In principle, the sizing ability could be further improved with the use of smaller diameter transducers. The technique has the potential for high reproducibility and accuracy. A method has been developed by which SAFT can be used with any normal beam transducer, flat or focused, extending its potential usage. Various computer algorithms and display techniques are being investigated on a continuing basis to extend and optimize the SAFT method. Ad-

vances were made in the use of SAFT for unique transducer arrangements, specifically for a novel noncontact LASER-EMAT transducer pair. The lateral resolution of defect images generated with this device were significantly enhanced by synthetic aperture focusing, after modifications were made to the basic SAFT algorithms to accommodate the unusual geometry.

Deconvolution of Ultrasonic Waveforms

The investigation of methods of increasing temporal resolution through deconvolution has continued. Wiener filtering in the frequency domain has been used extensively, and the Levinson recursion for the solution of a Toeplitz matrix system was implemented in Asyst to generate time domain least squares deconvolution filters. The maximum entropy technique commonly used in image processing was implemented in Asyst for one dimensional signals and applied to ultrasonic test waveforms. Improvements in temporal resolution were achieved, but the performance was not significantly better than the simple Wiener filter and the process was much slower.

Signal Processing for EC Applications

A project to investigate methods of sizing surface breaking defects typical of crevice corrosion pitting under fuel bundle pads was completed this year. The general approach was to model the scanning eddy current probe as a linear system where the output is produced by a convolution of the test parameter variation and an influence function characteristic of the probe. The focus of the project quickly became techniques of deconvolution; ie, given the probe output and test parameter variation, determine the probe's influence function or more difficult, given the probe output and influence function, determine the test parameter variation. Techniques investigated in detail included: a conceptually simple but effective time domain method known as the Allen-Grimm algorithm; a fast frequency domain method using a modified Wiener filter; and a flexible time domain method formulated as a matrix problem and solved using the iterative conjugate gradient method. The advantage of the latter method is that bounds may be placed on the solution domain based on a priori knowledge of feasible solutions. This may produce large performance increases as the deconvolution problem is generally ill-conditioned and not unique.

The deconvolution problem was investigated further during the summer by a student, Brian Reid. The Maximum Entropy method was explored because of its interesting goal. All previous methods sought solutions that minimized the least squares error between the modelled and observed output. A problem with this approach is that solutions can become oscillatory with little penalty (unless a boundary is encountered). The Maximum Entropy method seeks a solution with the minimum structure necessary to meet a given criteria on the same least squares error. As a result oscillations are penalized unless suggested by the observed data.

The deconvolution methods examined thus far show a lot of promise for application to many eddy current problems. Already some of the techniques have been used in the CIGAR-GAP project to determine the influence function of the probe and improve the pressure tube thickness compensation procedure.

Ultrasonic Rotary Shaft Position Encoder

A rotary shaft position encoder is being developed which in principle operates underwater, thereby eliminating the need for waterproof housings. The rotor consists of a number of vanes, each having an involute profile. An ultrasonic probe transmits pulses to the rotor which are then reflected back to the probe after a short time delay. This time delay depends on the speed of sound in the medium (water) and on the distance from the probe to the point on the rotor where the sound pulse is reflected. Since each vane has an involute profile, the change in this distance will be proportional to any change in angle. In addition, the ultrasonic beam will always hit the vane at right angles so that reflections will always go back to the probe. By measuring the time delay, special remote circuitry can determine the distance and thereby the shaft rotation. Additional counting circuitry can also be used to keep track of the rotation if it exceeds 90 degrees.

Electric Motor for Underwater Use

A motor is being developed which can operate continuously underwater without the use of seals. It consists of a magnetic stainless steel variable reluctance rotor which rotates inside a thin wall stainless steel tube, and a stator surrounding the metal tube to provide the rotating magnetic field. Since the stator is enclosed in stainless steel and potted in epoxy, this motor can remain submerged indefinitely without corrosion. Since this motor does not use a commutator, there are no exposed electrode surfaces which could lead to galvanic corrosion. Also, since there are no permanent magnets, it is unlikely that an accumulation of magnetic particles would cause the motor to seize up.

Non-intrusive Flow Measurement System for Annulus Gas System Tubing

A new method for non-intrusive flow measurement has been proposed for annulus gas system tubing. The basis of this method is to use a carbon dioxide laser (approx. 100 watts invisible infrared) to heat a spot on the annulus gas tubing and then monitor the resulting heat distribution with an infrared imaging camera. A further refinement of this approach is to use a computer for image analysis to produce a quantitative measure of the flow rate. For site implementation, a helium neon laser (approx. 2 mW visible red) would be used together with a standard television camera to aim the carbon dioxide laser. These components would be combined into a single optical unit which would be mounted on a remotely controlled tilt and orientation platform which would in turn be mounted on the fueling machine bridge carriage. The entire measurement process would then be remotely operated from outside the reactor vault. It is expected that this project will be approved for 1989.

Acoustic Emission Leak Detection and Signal Processing

A system consisting of endfitting with closure plug, short section of pressure tube, controllable leak rate fixture and pressurizing pump is used to simulate the Acoustic Emission (AE) signal of a through wall delayed hydride crack (DHC). The AE signal is monitored using modified equipment originally designed for AE detection of Grayloc seal leakage. The signal from the AE system is digitized using a Data 6000 A/D converter, connected to a Compaq 286 computer via GPIB/IEEE488 interface. Through Asyst software the acquired waveform can be displayed on a com-

puter monitor or stored in memory for past signal analysis. Asyst software is also used to control a multimeter used for monitoring signal from a pressure transducer in the system.

Ultrasonic Calibration

As an alternative to the unorthodox power check method for calibrating pressure tube ultrasonic inspections, a series of notches were put into sections of pressure tubes for evaluating calibration effects. The variables covered were: manufacturer; notch profile, orientation and location; length of cable, and presence/absence of a remote pulser preamplifier.

The results showed 1) that one manufacturer was better than the other two, probably because he used a different electrode; 2) that the RPPs saturated on the power checks, but not on the reference notches; 3) that the power checks were significantly higher amplitude than the notches, in contrast to previous results (probably due to different probe focal lengths).

Development of New Ultrasonic Instrument

After accessing what was currently available in ultrasonic inspection instrumentation, it was decided to commission the design and development of a new digitally controlled, high frequency, multi-channel UT set. A detailed functional specification was prepared and an external company was found that was capable of designing and manufacturing this instrument. A contract has been awarded and delivery of the final product is scheduled for December of 1989. The functional specification and intended uses of this UT instrument are fully described in a Research Division report.

1.2 Inspection Systems Development

CIGAR - Ultrasonic Calibration Upgrade

Conventional ultrasonic inspection practice requires the use of a calibration block of similar material and geometry to the part to be inspected. This block contains simulated defects of known size which must be detected by the inspection system. Use of the calibration block demonstrates that the system is functional and allows its sensitivity to be set relative to the simulated defects.

The CIGAR (Channel Inspection and Gauging Apparatus for Reactors) system does not directly use this system because design constraints do not allow a full sized pressure tube ring to be located in a position that can be accessed by the inspection head during an inspection. At present, a "power check" method is used to assure the system is operational, to detect changes in probe sensitivity and relate defect response levels to calibration notch sensitivities. This method has been criticized for various reasons and a new method based on the detection of simulated defects in an undersized zirconium ring is being investigated. Because the geometry of the ring is different from that of the pressure tube, it will still provide only a secondary calibration to the sensitivity of the reference defects in real pressure tube. However, it will provide a closer approximation of the conventional approach and should provide more consistent calibration results. Assessment of this new method will be complete in early 1989.

CIGAR – Gap Measurement

A pressure tube to calandria tube gap measurement system is currently being implemented on CIGAR. The eddy current probe is similar in design to that used for SLAR but the data processing and compensation for pressure tube thickness variations is improved. Data will be collected during the existing general helical scan (3 mm pitch) in order to obtain a detailed map of the thickness variations. The map will then be smoothed using an approximation of the spatial sensitivity of the eddy current probe in order to relate the focused UT thickness measurements with the broader eddy current response. Combining the smoothed thickness map with the output of the eddy current probe leaves a signal proportional to gap alone.

The form of the eddy current probes sensitivity profile, in both the axial and rotational direction, has been determined using deconvolution techniques and may be approximated by parameterized functions based on the electromagnetic interaction between the probe and pressure tube. The constants of the approximating functions are determined for each probe by a calibration procedure prior to use.

SLAP (Spacer Location at Power)

The goal of the SLAP project is to develop an eddy current garter spring detection system with performance similar to the current CIGAR system but suitable for use while the reactor is at power. The probe is similar in design to that used in CIGAR but it will be constructed of radiation resistant materials; ceramic coated magnet wire wound on a machinable ceramic form and potted with a ceramic adhesive. The entire probe will be encased in a thin skin of electron beam welded titanium to ensure that it remains water tight and intact during an inspection. A prototype of the probe and its support structure is currently being manufactured and should be ready for testing in the near future.

A New Concept for Inspecting Pressure Tubes SPIDER
(Self Propelled Inspection Device for Evaluating Reactors)

A new concept for inspecting pressure tubes is being considered. The basis of this method is a special inspection head equipped with electric motor drives which enable it to move axially into the pressure tube from a modified closure plug module which is loaded into the channel by the fuelling machine. A connector shaped like the end of an endfitting is picked up by the fuelling machine snout and connected onto the end of the modified closure plug to electrically connect the closure plug (and therefore the inspection head) to a console located outside of containment. The electrical connection between the inspection head and the modified closure plug is maintained by a flexible cord which uncoils as the inspection head advances.

What makes the SPIDER concept attractive is that a minimum of preparation is required prior to the actual inspection. This makes it possible to more efficiently use short periods of downtime for inspection when the station is shut down for other reasons. Radiation exposure is minimal, being limited to the installation and removal of the vault cable. No modifications to the fuelling machine are required. The quality of the inspection might also turn out to be superior. Since the inspection head drives are right next to the probes, detailed scans could be done without the backlash introduced by torsional windup in the drive rods as has been ex-

perienced by CIGAR and CIGARette. The inspection rate is likely to be favourable, compared with CIGAR, particularly if only a small section of the channel requires inspection. Even though it would be slower than PIPE, it would not require the 1-2 weeks of fuelling machine maintenance which PIPE requires. Therefore, it would still compare favourably if less than 100 rolled joints needed inspection.

CIGAR Multiplexer
(Channel Inspection and Gauging Apparatus for Reactors)

A multiplexer has been developed for use in CIGAR, making it possible to add more probes onto the inspection head by making more efficient use of the existing cable system. Because of the high radiation dose anticipated, reed relays were used instead of semiconductor switches. Ten units have been fabricated and tested to assure correct operation. One of these has been irradiated to 100 MRad and still operates normally.

SLAR - Wall Thickness Gauging System

The commissioning of the Pickering SLAR system has led to a number of changes in the design of the pressure tube/calandria tube gap measurement system to assure its reliable operation under all operating conditions. Wall thickness (WT) gauging is a subsystem of Gap Measurement and changes became necessary to make it work with the upgraded gap system. Originally, a single ultrasonic instrument was multiplexed between 4 WT probes. In the new system, two instruments are switched between two sets of probes and provisions have been made to add two additional instruments if this becomes necessary in future. At the same time, changes have been made to the Remote Pulser Preamplifiers (RPP's) that are used to boost the ultrasonic signals when long cables are used. The changes improve the impedance matching of the instrument to the cable to eliminate cable multiples and change the instrument bandwidth to better match the transducers being used. The changes have been made and commissioning and testing will take place in early 1989.

Pickering BLIP

Pickering BLIP (Blister and Spacer Location using PIPE) is a system for rapid pressure tube inspection in Pickering A reactors. In response to concerns about high deuterium levels found in P3-L09 system, a team with members from Design and Development, Operations and Research Divisions developed the BLIP system. It utilized modified fueling machines to enter the fuel channel, push the fuel string past the reactor centreline with a special inspection head that locates the position of garter spring spacers and used ultrasonic methods to detect cracked blisters on the outside of the pressure tube if they exist. After one half of the channel is inspected the fuel string is shifted to the other end of the reactor and inspection of the other half is performed. A complete channel inspection requires approximately 2 hours. A full reactor inspection would require approximately 30 days. The system was completed in early 1988 but has not yet been commissioned. First operation use is planned for Pickering Unit 4 in early 1989.

Research Division contributions to BLIP include development of the inspection systems, assembly and testing of the inspection heads, design and fabrication of the inspection system cabling inside the fuelling machines including underwater connections, extensive upgrades to the PIPE–BLIP control console to include additional equipment and development of BLIP data acquisition and display software.

Ultrasonic Cable Multiple Studies

A study to determine the cause of ultrasonic cable reflections found that they are due to impedance mismatch between the ultrasonic instrument and the co–axial cable being used. On most instruments matching can be achieved by adjusting the "damping" control, which changes the output impedance while narrowing the pulse width (ie, reducing the pulse recovery time constant). Most cable reflection problems had been noted on systems employing long cables and remote pulser preamplifier's (RPP's), eg CIGAR and SLAR. The RPP's have no damping control and were inherently poorly matched to the cable resulting in the reflection problem. After consultation with the manufacturer, changes have been implemented to eliminate cable reflections when these instruments are used.

Automated Ultrasonic Inspection
Technique Development For Steam Generator Tube

The objective of this program is to develop an automated ultrasonic inspection device and a UT technique for the inspection of steam generator tubes. The inspection concerns the steam generator tubes at and immediately above the tubesheet area.

The ultrasonic investigation has focused on developing a multi–probe single axis (axial) system to perform volumetric inspection. It is anticipated that this probe will provide fast, single pass, volumetric scanning for flaws and circumferential cracking around the tube O.D. Manufacturing of a specially designed UT probe with multi–elements is currently underway. It is also considered that another UT probe with multi–elements will be needed to measure wall thickness and detect sludge pile location.

Development of a mechanical delivery system for this S.G. tube inspection is in progress. Two delivery concepts which are being considered for the inspection are (1) a single axis motion for the multi–element probe and (2) a two axis motion system. A two axis system provides both rotation and axial motions for the probe whereas a single axis system only drives the probe in and out of the S.G. tube. This UT scanner will be specially designed to inspect the area at and above the tubesheet. It is believed that the axial scanning length of the probe can be modified in the future to perform a full length tube inspection. To meet different inspection requirements, mechanical devices based on the two delivery concepts may be developed in parallel.

Software development has begun in the area of motion control for the probe positioning system, data acquisition, processing and presentation. The possible development of an ultrasonic instrument suitable for steam generator tube inspection is currently under investigation.

Pickering PIPE Laboratory Tests

Functional Tests

A full size mechanical test rig at Research has been used to evaluate the Pickering PIPE transducer carrier and to simulate the operation of a Pickering fuelling machine. The following tests were conducted.

- mechanical connection
- winch motor pressure vs. cable tension test
- cable connector continuity test
- carrier and ram head alignment check

Transducer Carrier Cycling Testing

The purpose of the cycling testing is (i) to determine the overall effect of mechanical backlash on the rotary scan; and (ii) to assure that the carrier is operating within the performance & durability expectations.

An MTS hydraulic cycling machine and a test fixture for holding the carrier and water provided the cycling and monitoring capability for the carrier cycling tests.

During several cycling tests, the PIPE transducer carriers failed to operate properly. It was found that the mechanical failure encountered was caused by some mechanical design problems. Several mechanical modifications have been made to the six transducer carriers.

Prior to the final cycling test, six Pickering PIPE transducer carriers were lubricated with Moly grease. In a constant velocity cycling mode, the carriers performed much better than before. When the shielding module was also removed, stick/slip condition at the beginning and the end of rotation was substantially reduced.

On-Power Ultrasonic Inspection

An EMAT (ElectroMagnetic Acoustic Transducer) device, custom made for pressure tube inspection, has been under development all year at Magnasonics in New Mexico. EMAT devices are made of a magnet and an eddy current coil, so they can be made high-temperature and radiation-resistant in principle. Unfortunately, EMAT devices are inherently very low signal amplitude, so they require considerable tailoring.

The initial Lamb (plate) waves used in this pressure tube EMAT device proved to be highly damped by the water in the tube, so further development of the transducer was necessary. The manufacturer subsequently changed to a n=4 mode focussed Lamb wave, and obtained the specified signal-to-noise ratio on the appropriate notch. The turnkey device should be shipped early in 1989.

Bioshield Inspection

An ultrasonic inspection head has been developed as back-up for the remote field eddy current system for the Pickering bioshield piping. The bioshield piping is known to be leaking, but the deterioration mechanism is unclear. The ultrasonic

module contains axial and circumferential shear wave and normal beam probes, hopefully to detect any type of defect. The module will be coupled to the Sheridan Park drive mechanism, which consists of a long coiled cable pushed up the bioshield piping. The module was tested on standard notches, which showed that signals could be interpreted by the operator, but that head rotation was not feasible. The first, and most important, module was for 1.5" piping, and a second has been modified for 2.5" piping. The main problem with the module design has been shrinking the diameter sufficiently to pass round a tight 90 degree bend.

Remote Inspection of Container Final Closure Weld

Most of the work has been on finalizing the robotic inspection of the prototype titanium diffusion bond. There were a number of technical problems with the mapping/scanning software and the robot's operating system that have slowly been debugged. At year's end, virtually all the known problems had been solved, and final scans are expected in 1989. The testing has showed that one of the major limitations of the robotic inspection system is its speed. The mapping procedure in particular takes so long that it would be impossible to scan a container in time to keep up with production. This problem is being addressed separately.

As a result of the slow rate of robotic scanning, a more rapid technique has been investigated in conjunction with Queen's University. This technique uses laser-generated ultrasonic plate waves to travel through the diffusion bonds. The waves are detected by a non-contacting EMAT transducer. If the diffusion bond is sound, the plate waves "decay" due to the increased thickness. If there is a disbond, the plate waves propagate through the single layer, and are detected. A spectrum analysis is performed on the received wave, and the differences between a bond/disbond can be readily detected using a cepstrum analysis. This technique offers a rapid, non-contacting technique for detecting disbonds.

Automated Data Collection System

A new laboratory data acquisition system was developed in 1988 which is capable of controlling the motors on a two dimensional scanning rig, collecting both analogue and digital data, digitally processing that data, and generating a variety of data displays. This system is primarily targetted towards ultrasonic data collection but is independent of the type of data being collected. The system is being extended this year to include more powerful signal processing techniques. Support for additional data collection hardware will also be provided. A full description of this system is available in a Research Division report.

1.3 Pressure Tubes

Probability of Blister Detection using SLAR FastScan Probes

The TRAC 11 blistered pressure tube was scanned using the SLAR ultrasonic blister detection system, and blisters were classified as detected or not based on signal amplitude. Then twenty blisters were metallographically sectioned, and a plot of signal amplitude vs. crack depth made. Crack depths ranged from 0.09 mm to 0.26 mm. The minimum crack depth detected by ultrasonics was 0.15, but one (angled) crack of 0.26 mm was not detected. The best regression correlation was obtained with individual blister crack area, not crack depth.

Overall, the estimates of probability of detection were as follows: 1) Using a more appropriate two-population approach, the overall estimate was that the system would have a 71% confidence in detecting an isolated blister crack 0.37 mm deep. 2) Using all the data as an alternative, the overall estimate was that the system would have 95% confidence in detecting an isolated blister crack 0.41 mm deep. The probability of detecting a string of blisters rapidly approached 100%. However, the data base was too limited to merit further study.

Measurement of Hydride Platelet Concentration by Ultrasonics

Further work on scanning acoustic microscopy imaging of hydride platelets has been performed, both at UKAEA Harwell and at Sherbrooke University, Quebec. Sherbrooke have thoroughly characterized Zr-Nb material, and have attempted to image platelets at very low frequencies (10-30 MHz) using customized lenses developed from their characterization results. The images obtained at low frequencies have been poor, so Sherbrooke have been considering moving up to frequencies around 90 MHz. Similarly, Harwell have been reducing their frequencies from 370 MHz to the 90 MHz region. Sherbrooke are currently working on imaging platelets on curved tubes through the oxide.

Queen's University have been attempting to measure hydride platelet concentration using birefringent normal beam shear waves. These waves are generated by putting a high frequency (20-30 MHz) contact normal beam transducer on the specimen, twisted at an angle of 45 degrees to the axial direction. Two normal beam shear waves are generated, one polarized in the axial plane and the other in the circumferential plane. The birefringent shear wave technique readily showed the presence of uncracked blisters since the slower shear wave was visibly slowed even more in the blister region. The technique has not been quite so successful with measuring platelet concentration, though work continues.

As a spin-off from the Queen's work, ultrasonic shear wave methods of detecting uncracked blisters are being investigated. Pitch-catch B-scans using 45 or 70 degree probe pairs have both shown potential.

Magnasonics in New Mexico have been investigating Differential Velocity Measurements (DVM) in partially hydrided tubes. For DVM, two (or more) waves of different polarization are sent down identical metal paths. One wave is more affected by the property than the other, and the difference in velocity offers a quantitative measurement of the parameter of interest. DVM is used for measuring stresses, for example, but the technique has limitations.

For hydride platelet concentration measurements, a pressure tube sample was sent to Magnasonics with a partially hydrided region of 60 ppm. Magnasonics built two EMAT (ElectroMagnetic Acoustic Transducers) devices to generate polarized shear (SV and SH) waves. These waves showed no velocity difference in the unhydrided region, but a significant difference in the hydrided region. This was a very encouraging result since EMAT DVM devices offer a practical, rapid measurement technique.

Unfortunately, when five more pressure tube samples were sent to Magnasonics, preliminary results showed little velocity change between the hydrided and unhydrided regions. This could be due to changes Magnasonics made in the

transducers, edge effects that were highly visible with this particular set-up, or the DVM technique could be measuring the residual hydride layer from electroplating that was only left on the first tube. Further research should answer this question.

Inside Surface Oxide Characterization

Attempts have been made to measure the thickness and density (porosity) of ID oxides using high frequency spectral analysis. In this technique, resonances should occur within the oxide (if greater than about 1/4 wavelength), and these should show in the ultrasonic spectrum. The amplitude and spacing of these troughs is a function of the acoustic impedance mismatch and thickness respectively.

Due to equipment limitations, specially-prepared, thick, fast-grown oxides were examined. The results showed that oxide thickness was measurable under good conditions, but density is difficult to estimate. Unfortunately, the oxides showed rough surfaces and layering, which severely hampered the technique. Nevertheless, several signal processing innovations (spectral analysis, division by averaged reference spectra, and windowing) have been developed, which show some potential for characterizing oxides.

Detection of Oxide Cracking

An acoustic microscopy approach was used to detect cracking on inside surface oxides in pressure tubes. A simple acoustic microscope, with lenses custom-made for zirconium, was assembled in the laboratory by a technician from Sherbrooke University. He then scanned several different oxide specimens with varying degrees of cracking using the V(z) and linear scan techniques. The images showed that either surface topography or cracking could generate contrast, though the topography was the dominant effect. Acoustic microscopy obviously has potential for detecting cracking, but the oxides are far from perfect specimens. A variety of other items, such as coins, were scanned to demonstrate the potential acoustic microscopy.

Measurement of Blister Crack Depths

Work continued on measuring blister crack depths using ultrasonic crack tip diffraction. Initially, three tight axial fatigue cracks and two cracked blisters were examined using the laboratory set-up. Using several signal processing techniques, depths were estimated to within the required accuracy of $\pm$ 0.1 mm. Subsequently, a fixed module was built, using 45 and 55 probe combinations. This showed limited success on the TRAC 2 blistered tube because of the tube's rough inner surface and very shallow cracks. Currently, the module is being used on another tube containing several large cracked blisters, with much more success. The results will be analyzed in 1989, prior to further developing an in-service system.

An investigatory contract was given to Queen's University to determine ultrasonic ways of measuring depths of pseudo-delayed hydride cracks from the inside. Four different ultrasonic techniques showed promise, with the two time-of-flight approaches giving the most accuracy. Depth measurements on Hubert's Crack (a tight inside surface fatigue crack) showed a good correlation with previous techniques, though the signals were weak.

Darlington 1 pressure tube R07 was shipped to Research for investigation of two defects detected during the manufacturing and installation. The first defect would have been readily detected by CIGAR, and was sized from the outside surface using the 100 MHz probe. Despite repeated scanning, the second defect could not be found, and this portion of the tube will be shipped to CRNL to confirm the observation.

Darlington – Pressure Tube Elongation Measurement

Monitoring equipment is required to periodically measure the elongation of pressure tubes at Darlington NGS. Because of certain differences in the reactor designs, the measurement equipment for Darlington has been designed differently from those for the Pickering and Bruce reactors. This measurement equipment includes stud measurement tools, theodolite target devices, ultrasonic S.T.E.M. heads (Scanning Tool for Elongation Measurement), and feeder clearance tools. All tools are designed to be used in reactor shutdown condition.

These tools have been designed, built and tested at Research Division. The theodolite target devices and the stud measurement tools have been successfully used at site. Following two field tests at Pickering NGS, two ultrasonic STEM devices for Darlington NGS have been modified to provide RS422 in addition to the standard RS232C data interface capability. It is anticipated that the STEM devices will be used in February 1989.

NDE of Yttrium Hydrogen Sinks for Pressure Tubes

Ultrasonic evaluation of prototype zirconium clad Yttrium hydrogen sinks was performed for AECL engineering company in 1988. It involves measuring the thickness of the zirconium cladding and determining the quality of the bond between the two materials in this HIPed (Hot Isostatically Pressed) part. Although we can easily perform these tests with laboratory equipment, outside NDE firms and others approached by AECL have not been able to perform them. Since there is no plan to use the hydrogen sinks in the near future, we will continue to test prototype specimens for AECL as required.

Post Removal Ultrasonic Inspection of P.T. B1–S04

In April 1988, CIGAR inspection of pressure tube B1–S04 revealed a number of large ultrasonic indications in the tube. The tube was removed and sent to AECL–CRNL for evaluation. Research NDE personnel set up a computer controlled scanning rig with a CIGAR transducer module in the NRU spent fuel bay to perform more detailed ultrasonic examination of the defects. The object of the exercise was to collect both time and amplitude information using a number of techniques in order to evaluate their usefulness for defect characterizing and sizing. Ultrasonic B–Scan and C–Scan images were obtained using normal beam, pulse echo shearwave, pitch–catch shearwave on opposite and right angle pairs of probes, and pitch catch between shear and normal beam probes. The data has been analyzed but due to the complex nature of the defects, predictions of defect characteristics and size are uncertain. Destructive examination of the defects is in progress at CRNL. When these results are available the merit of the various UT techniques will be reassessed.

Small Pressure Tube Rig Upgrades

Compumotor stepping motors and Heidenhiem high resolution optical encoders have been fitted to the rotary and x, y and z axis drives of a small scanning rig that is used for pressure tube ultrasonic evaluation. This rig is now compatible with the newly developed Compaq 386 based data acquisition and imaging system and it will be used for CIGAR defect characterization and sizing studies.

EC Measurement of H_2/D_2 Concentration

The goal of this project is to develop a non contact eddy current technique to accurately monitor the change in pressure tube resistivity over a temperature range of 20°C to 400°C. The work by K. Tashiro in Materials Integrity has suggested that an estimate of the H_2/D_2 concentration may be made from the resistivity vs. temperature plots.

During the past year a design concept was developed which attempts to minimize the effects of any undesirable influences on the eddy current signal. With the aid of a computer model, a probe design was selected that achieved a strong linear response to bulk pressure tube resistivity while minimizing the response to dimensional changes. The probe is designed to be water cooled and insulated from the heated pressure tube in an effort to minimize the temperature change experienced by the probe. It is constructed from low expansion ceramic materials to minimize the effect of any temperature change that it does experience.

A short mock-up of a fuel channel has been constructed and will be used to evaluate the response of the prototype probe. It has a water loop to simulate shut down PHT coolant flow, a large reservoir to simulate the moderator and numerous thermocouples to measure the temperature distribution. A scanning data acquisition system has been developed to monitor the thermocouples and display the channel temperature as a function of position and time.

1.4 1989 Work Plan

The 1989 NDE Unit Work Plan will concentrate on the primary pressure boundary (mostly pressure tubes), as in previous years. Major long-term projects include: work on H/D measurement in pressure tubes (both eddy current/resistivity and ultrasonics); on power eddy current inspection for garter springs (SLAP); ultrasonic crack depth measurements in pressure tubes, primarily blisters; an on-power EMAT ultrasonic inspection device; digital deconvolution techniques for defect characterization; synthetic aperture focussing for several applications; acoustic emission detection of leaking pressure tubes; and development of a rapid steam generator inspection system (all COG funded). Development of Pickering BLIP will continue. CPS will fund the research aspects of the laser-heated infra-red system for measuring annulus gas flow rates in the pig-tails, plus work on detection of the new garter springs, some steam generator work and miscellaneous other short-term projects. Other research work includes improvements in the 100 MHz ultrasonic inspection system (both in transducer manufacture and in calibration); development of a novel high frequency ultrasonic pulser; defect characterization by ultrasonics; CIGAR sag development; manufacturing inspection assistance; and further signal processing. Remote inspection of nuclear used fuel final closure welds will continue. And, as always, there will be unforeseen firefighting projects.

2.0 FRACTURE MECHANICS RESEARCH AND APPLICATION

2.1 Darlington Leak-Before Break Program

Darlington Leak-Before-Break; Fracture Analysis of Reactor Inlet and Outlet Headers

Analyses to date used models of the reactor inlet and outlet headers (RIH and ROH) containing through wall cracks. A trial and error procedure was used to size the crack to give a predetermined leak rate. However, the opening deflections were obtained from shell models. Since the predicted sizes were suspiciously large, a parametric three-dimensional (3D) study of both headers was performed. The result is a pair of crack length versus leak rate curves.

New 3D models, based both on the detectable (RCL: "reference crack length") and twice RCL were analyzed to give J-integral values, based on deformation plasticity theory.

A new set of tensile and J-resistance material data was obtained from Dr. E.T.C. Ho (Materials Integrity Section) and Dr. B. Mukherjee (Nondestructive and Fracture Evaluation Section) for the branch material of the RIH and ROH. The tensile data exhibited lower yield and ultimate stresses than that of the 22" NPS Sch 100 pipe previously thought to be representative. The J-resistance curves were noticably higher.

The tensile data was curve fitted according to a Ramberg-Osgood form for use in deformation plasticity based finite element analysis.

Analyses, using the new tensile data are under way. Tentative results are that, although the material J-resistance curves have "improved", the applied J (ie, calculated values for the headers) have increased as a result of the lower stress-strain curves.

Fatigue Crack Growth Computer code for Darlington Leak-Before-Break Project

Predictions are being made of the fatigue crack growth of postulated part-through wall cracks in the primary heat transport piping as a part of the "defense-in-depth" strategy of the Darlington LBB project. Safety margins against fracture initiation on the final flaw size are also predicted. This involved the development of a computer code, FCAP Version 1.0, to perform the calculations for an entire piping system.

This computer code was modified to Version 1.1 to include more user input options, and changes to the procedures used to calculate stresses in weldments. The scope of the internal library of fracture toughness properties was increased. These modifications allow more general applications of the code to carbon-steel piping systems, rather than being restricted to the Darlington large-diameter primary heat transport system.

Validation of FCAP Version 1.1 has been completed. The validation exercise involved performing complex calculations to test essentially all of the functions in the computer code. This work was performed for the Mechanical Design Department, Design and Development - Generation. This computer code has been installed on the VAX mini-computer in Mechanical Design.

2.2 Pressure Tubes

Technical Basis and Computer code to Determine Fitness for Service of Zr-Nb Pressure Tubes

A draft version of a technical basis document for the evaluation, for continued service, of Zr-Nb pressure tubes containing flaws has been written. The evaluation is based in the application of fracture mechanics methodologies. A first version of an IBM-pc compatible computer code based on the draft evaluation document has been completed. Currently, the computer code only handles axial flaws. Some validation of the code has been completed.

It is anticipated that modifications will be made to the computer code as progress is made in the Zr-Nb pressure tube flaw evaluation methodologies. This work was carried out for the Chemistry and Metallurgy Department of Central Nuclear Services.

Crack-Tip Stress Fields Under Unloading

The Delayed Hydride Crack (DHC) velocity in a Zr-Nb laboratory fracture mechanics specimen is known to decrease significantly or arrest when the load on the specimen is partially reduced. The decreased velocity is in some cases less than the corresponding velocity if the specimen were loaded monotonically up to the lower load level. The cause of the reduced DHC velocity or arrest is considered to be residual compressive stresses at the crack tip in the partially unloaded specimen. Two-dimensional finite element calculations were performed to quantify these residual stresses in the partially unloaded specimens. Compressive stresses exceeding the magnitude of the material's yield stress were predicted to occur at the crack tip after the specimen was unloaded to one-half of the peak load.

This work was supported by the Chemistry and Metallurgy Department of Central Nuclear Services to facilitate the analysis of experiments carried out in the Materials Integrity Section.

Elastic-Plastic Finite Element Analysis of Notched Zr-Nb Tension Specimens

In support of experimental work being carried out in the Materials Integrity Section, two- and three-dimensional elastic-plastic finite element analyses were carried out for notched Zr-Nb tension specimens. The analyses involved the calculation of the variation of stresses and strains throughout the specimen at various load levels. Three different notch geometries were included. The effects of specimen unloading was also quantified in support of low-cycle fatigue experiments.

The three-dimensional results for notch-tip stresses at the centre of the specimen were close to the two-dimensional plane-strain results, while the three-dimensional results for notch-tip strains were up to 75% higher. Upon unloading, compressive stresses exceeding the material's yield stress occurred at the notch tip.

Predictions of the notch-tip stresses and strains were also performed with an approximate analytical technique. Notch-tip stresses from the analytical technique were close to the three-dimensional finite element results at the centre of the specimen, but the analytical method predicted notch-tip strains which were 35% higher. This work was funded by the Candu Owners Group.

Effects of Hydride Morphology on Zr-2.5Nb Fracture Toughness

Tests were performed on specimens prepared from a flattened and hydrided strip of Zr-2.5Nb pressure tube containing 130 ppm hydrogen as radial hydrides. This structure had a hydrogen continuity coefficient (HCC) of 0.73.

Brittle behaviour was observed at all test temperatures up to 280°C, although ductile behaviour was observed at both 270 and 280°C, and there was a general increase in toughness, indicating a transition region above 240°C. The toughness transition occurs gradually, and does not appear to be fully complete at 280°C.

All these specimens were held at the test temperature for a time judged sufficient for hydride dissolution to the equilibrium concentration. Other results have indicated that varying the hold time can significantly affect the test result. Lower toughness measurements will result if the hydrides are not at equilibrium.

Three other hydride morphologies were produced in pressure tube sections. All have relatively low hydride continuity coefficients (HCC values) at different hydrogen concentrations - approximately 50, 80 and 200 mg/kg. Half of the test specimens from these structures are currently being tested, while the other half are being irradiated at CRNL in an effort to determine the combined effects of hydrides and irradiation.

Fracture Testing of Pressure Tubes Containing Surface Cracks

The objectives of this program are primarily to study the behaviour of surface cracks in pressure tubes, and to determine whether the initiating location of a surface crack affects the likelihood of leak before break.

A number of experiments have been conducted on tubes containing external axial surface cracks. The cracks were produced by fatigue-sharpening EDM starter notches using specially developed precracking software. The cracks are then pressurized to failure while monitoring the crack mouth opening displacement (CMOD) via a clip gauge, and the crack depth via d.c. potential drop. The results are being analyzed to determine the relationships between the experimentally measured parameters and the crack size and applied pressure at ligament rupture.

Because of the danger of damaging a clip gauge during tube rupture, a technique is being developed to measure CMOD and CTOD (crack tip opening displacement) using a video camera viewing the crack through a microscope focussed on a mirror.

Images can be captured at regular intervals by the computer, and measurements performed via an edge-detection algorithm. This system is currently being installed.

Future tests will be performed on hydrided material, in which the surface cracks will be grown by DHC (delayed hydride cracking). These tests will be performed on ordinary tube sections and on specimens with simulated end fittings to determine the effects of constraint on the likelihood of crack penetration prior to reaching an unstable size.

Fatigue Crack Growth of Zr-Nb Pressure Tube Material

The objective of this COG program, which is jointly being carried out at Ontario Hydro and CRNL, is to assess the fatigue crack growth rate behaviour of Zr-2.5Nb pressure tube material in a simulated CANDU PHTS environment. Work at Ontario Hydro will concentrate on evaluating environmental effects, such as high dissolved oxygen concentrations, while work at CRNL will address effects of irradiation on the fatigue crack growth rate.

The test program will examine a large number of test variables which may affect the fatigue crack growth rate. A second autoclave was purchased and delivered in December 1988 in order that these variables could be examined in a reasonable time frame.

Work was concentrated on developing a loading rod seal in the autoclave which could operate continuously for long periods of time without any significant leakage. A loading rod sealing assembly with a water-cooled housing was designed, fabricated, and commissioned successfully at 300°C and 12.4 MPa. Fatigue testing will commence in January 1989.

2.3 Plant Materials

Fracture Toughness of Heavy Water Plant Blistered Steel

Many vessels currently in service at BHWP possess varying amounts of damage from internal hydrogen blistering which may be degrading the pressure containment. A fracture toughness test program was initiated on blistered steel received from BHWP to aid in establishing safe operating limits and retirement criteria for hydrogen blistered pressure vessels.

To date fracture toughness tests have been carried out at room temperature on specimens of damage-free and blistered steel material in both the hydrogen charged and uncharged conditions. Testing was performed at a loading displacement rate of 8.3×10^{-3} mm/s or slower in order to ensure that effects of hydrogen were revealed.

Preliminary results indicate that the crack growth resistance of material charged with hydrogen is specifically reduced at 21°C. Damage in the form of blisters appears to have little affect on the crack growth resistance.

Fracture Toughness Properties of A216 Gr WCB Cast Steel

The life assessment work carried out on Unit 3 of Lambton TGS revealed cracks in the boiler circulating pumps. To determine the severity of the cracking CTS requested the Fracture Mechanics Unit to carry out a structural integrity assessment of these components. This assessment required fracture toughness properties of the component material. For this reason, the present study was conducted to determine the fracture toughness of A216 Gr WCB cast steel at room temperature (24°C) and the normal thermal plant operating temperature of 366°C.

Material from the damaged pump casing was not available for testing. Instead, a nominally identical grade of cast steel, consisting of a 4.3 cm thick flange, was used for test purposes.

Results showed that the fracture toughness, as reflected by the J-resistance curves, was similar at 24 and 364°C. The tests at 24°C exhibited a transition to cleavage fracture after some ductile crack growth and was indicative of material behaviour in the middle part of the Charpy transition temperature regime. Valid ASTM initiation fracture toughness J_{Ic} values could not be determined at 24°C because of the transition to cleavage fracture.

A fractographic examination of the specimen fracture surfaces was also performed to determine the fracture mode in local regions and measure the stretched zone width. The mode of ductile tearing at 24°C and 364°C partially reflected the dendritic structure of the cast material. The stretched zone width was measured and used to estimate the initiation fracture toughness. Based on these measurements, J_{Ic} was estimated to have a minimum value of 115 and 92 kN/m at 24 and 364°C, respectively.

2.4 Flaw Assessments

Evaluation of Flaws in the Lambton TGS

Flaws have been detected in the boiler circulation pump casings, discharge valve bodies and pump suction manifold in Units 1 and 3 of the Lambton TGS. Flaws have also been detected in the inlet economizer header in the Lambton TGS Unit 1. The deepest flaws were repaired. Fracture mechanics evaluations were performed to assess the safety margins for these components.

The fracture mechanics evaluations required finite element analyses to determine stresses. Stresses due to internal pressure, deadweight and thermal expansion were calculated. Stresses in the inlet economizer header were taken from a previous finite element analysis. The stresses were then input into fracture mechanics models to calculate the crack-driving-force stress intensity factor. The material's fracture toughness was also required, and this was measured from laboratory tests performed in-house on sample material taken from the Lakeview TGS.

All components had acceptable safety margins, and Lambton Units 1 and 3 were put back into service. This work was carried out for the Chemistry and Metallurgy Department of Central Thermal Services.

Modifications to In-House EPFM Flaw Evaluation Computer Code

An in-house computer code, EPFLAW, was previously written to perform flaw evaluations using Elastic-Plastic Fracture Mechanics (EPFM). This code contained a single flaw model of a circular cylinder containing an axisymmetric 360 degree circumferential edge crack under a remote tension which was treated as a primary stress. This model has been modified to include membrane and through-wall bending secondary stresses due to weld residual stresses or thermal stresses. Models of axial flaws in an internally pressurized cylinder have been added to the code. Axial flaw models with both an infinite aspect ratio (flaw length divided by flaw depth) and a finite aspect ratio have been included. Both axial flaw models also contain membrane and through-wall bending residual or thermal secondary stresses.

Validation and documentation of the computer code has been completed. This work was carried out with the support of the Chemistry and Metallurgy Department of Central Nuclear Services. A copy of the code was sent to CNS for conversion to the IBM-pc format.

2.5 1989 Work Program

The work program of the Fracture Mechanics Unit will concentrate on the structural integrity of primary and secondary pressure boundaries. Work will continue on both experimental and analytical aspects of fracture mechanics.

Fracture testing of pressure tube specimens containing surface cracks will continue using the newly commissioned burst test facility. The primary objective of this project is to determine the criteria affecting the rupture of thin ligaments leading to wall penetration of DHC surface cracks. The reason for crack tunneling due to DHC in pressure tube is not clear. Analytical studies will also continue to model the crack tunneling behaviour and final ligament collapse of surface cracks in a pressure tube from an applied mechanics viewpoint. The project to determine the effects of variations in hydride structure and hydrogen concentration on fracture toughness of both unirradiated and irradiated pressure tube material will continue in cooperation with CRNL. The resulting "fracture map" will permit accurate prediction of toughness over the wide range of condition anticipated during the pressure tube operating life. The effect of water environment on the fatigue life and crack growth rates will be determined on both irradiated and unirradiated pressure tube material, again in cooperation with CRNL.

Technical consultation will be provided to Central Production Services for evaluation of flaws in nuclear and thermal plants. Material tests will be conducted on A106B piping steel at liquid nitrogen temperature and on A212 Gr B steels from Lakeview TGS headers at operating temperature to provide material information for structural integrity during freeze plugging and thermal plant life extension, respectively. Our commitment to Darlington Leak Before Break program will be completed by July 1989.

III – SUPPORT TO THE EXTERNAL COMMUNITY

The Section provided support to Canadian organizations by making research staff and laboratories available to students for their fourth year and post-graduate projects. The technical support and consultations were also provided by the Section staff to Canadian, American and International organizations. A few examples of this involvement are listed below.

University of Toronto

Mr. K.-E. Lindenschmidt continues his studies on blister crack sizing with Mike Moles and Professor A.N. Sinclair of the University of Toronto. Professor Sinclair and Mukul Mukherjee gave a course and a workshop on Elastic Plastic Fracture Mechanics at the University of Toronto. The workshop was attended by participants from AECL, Ontario Hydro, Boeing and Syncrude.

ASME and ASTM

Doug Scarth was invited to become a member of the ASME Boiler and Pressure Vessel Code, Section XI, Flaw Evaluation Committee. This was due to Doug's active participation in the ASME Piping Flaw Evaluation Task Group and the working group on Flaw Evaluation over the last two years. The Fracture Mechanics Unit continued to take an active role in the activities of the ASTM E-24 committee on Fracture, the Canadian Committee for Research on the Strength and Fracture of Materials (CSFM) and the International Council of Fracture.

NDE Institute of Canada

Members of the Section continue to support the NDE Institute through donations of personal time to teaching NDE subjects, in providing advice on technical matters and in acting as trustee to the Institute.

United Nations

At the request of the United Nations Industrial Development Organization, John Baron presented a 2 day course on nondestructive evaluation in Barbados.

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